An Introduction to Liquid Crystals

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This book is dedicated to my family:
to my grandparents, Tommaso and Carmela Frate,
to my parents, Richard and Mary DiLisi,
to my siblings, Rick DiLisi, Carla Solomon, and Jennifer Newton,
to my wife, Linda,
to my daughter, Carmela,
and
to the wonderful creatures who inhabit our home.

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Preface

Liquid crystals make today's modern world of technology possible. Flat-screen TVs, lightweight laptop computers, cellular phones, automotive dashboards, and a wide variety of electronic instrument panels all have liquid crystal displays (i.e. 'LCDs') embedded in their construction at some level. When you make copies at the office, a liquid crystal display provides the interface between you and the copier. When you watch the local morning talk show while pacing anxiously in the dentist's waiting room, you are probably watching a light-weight, wall-mounted liquid crystal monitor to get your information. When you pull out your cellphone to show friends and relatives selfies from your latest vacation, be sure to thank the technologies buried within the phone's liquid crystal screen for the rich colors and clear images that you see.

Practically every display technology in use today relies on the flat, energy-efficient construction made possible by liquid crystals. These displays provide visually-crisp, vibrantly-colored images that a short time ago were thought only possible in science fiction. Although liquid crystals are known mainly for their use in display technologies, they also provide many diverse and useful applications: adaptive optics, electro-optical devices, films, lasers, photovoltaics, privacy windows, skin cleansers and soaps, and thermometers [1–4]. The striking images of liquid crystals changing color under polarized lighting conditions are even on display in many museums and art galleries—true examples of *'science meeting art.'* Although liquid crystals provide us with visually stunning displays, fascinating applications, and are a rich and fruitful source of interdisciplinary research, their full potential may yet remain untapped.

At the Tate Liverpool Museum of British and International Modern and Contemporary Art, the exhibit *'Liquid Crystal Environment,'* is made by placing thermotropic liquid crystalline samples on five projectors fitted with polarizing filters and projecting their images onto two walls. The slides are heated and cooled to induce phase changes within the samples. The slides are also rotated atop their projectors. The phase changes and rotation of the samples are accompanied by vivid shifts in color that create the illusion of movement.

This book stems from the introductory section of my PhD thesis titled, '*Oligomeric Liquid Crystals: Viscoelastic Properties and Surface Interactions*' [5]. Although the experimental techniques explored in the thesis focused on measuring the impacts of the molecular length and shape on the elastic deformations of various liquid crystalline systems, its introduction provides a solid foundation of liquid crystals for the novice investigator. When the thesis was written, the introduction nicely summarized the basic underlying physics, classifications, and properties of these fascinating systems … today, it still does. Thus, I have taken this material, updated the content and diagrams, and packaged it into this introductory-level text. Finally, I highlight that two entirely new features have been added to the treatment. First, like any specialized field of study, research into liquid crystalline systems has its own lexicon. Thus, the etymology of all newly-defined, specialized terms has been included in this text. Research shows that students learn and retain information when such words, especially in STEM-fields, are accompanied by etymological and historical origins. Personally, I simply find that knowing the roots of new terminology, especially as I attempt to absorb the nuances of a new field of study, makes for a richer and more meaningful learning experience. Secondly, given the growing popularity and utility of liquid crystals, I have added a final section on the experimental techniques used to probe these systems.

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Charles Rosenblatt, PhD, Professor of Physics, Case Western Reserve University, and Ohio Eminent Scholar in Condensed Matter Physics. As my graduate advisor, Chuck guided the research from which my PhD dissertation sprang and from which this book evolved. Without Chuck’s subtle physical insights, experimental expertise, and mentorship, this book would not be possible. Much of the work appearing in these pages was the result of countless sleepless nights by the students studying in Chuck’s Liquid Crystal Research Group. Special thanks goes to my former lab-mates, **Zili Li**, **Minhua Lu**, and **Karl Crandall**, as well as to **Ian Nemitz**, on whose dissertation committee I served. Now scattered across the globe, these folks brought laughter to the daily grind of laboratory work. A finer crew was never assembled.

Vance Williams, PhD, Associate Professor and Chair of the Department of Chemistry at Simon Fraser University. Dr Williams graciously supplied the striking images of liquid crystalline samples that fill the pages of this book. He stands as a true example of international collaboration in the interest of advancing science.

My able and supportive team of publishers: **Susanne Filler** and **Melanie Carlson,** from Morgan & Claypool Publishers, who turned the idea of this book into reality; **Karen Donnison,** from Concise Physics, who worked long, thankless hours to produce the figures and diagrams contained in this book; and **Chris Benson** and **Heather McKenna,** from IOP Publishing, who work magic (literally overnight) to turn the chicken scratch of the initial drafts of this manuscript into the neat, polished version you see before you.

My graduate assistant, **Alison Chaney.** Although her expertise lies in the area of School Psychology, Alison read … and re-read … the many iterations of this manuscript, using her eagle eyes to catch the countless typographical and grammatical errors that riddled its initial versions. Alison’s work was very necessary and much appreciated.

My friend and the finest engineer walking the planet today, **Richard Rarick**. Rick’s interests in etymology sparked my own inclusion of word-origins in this book. His craftsmanship as an engineer and dedication to the art of teaching manifest themselves in several sections of this text. Rick’s attention to detail is simply unparalleled.

Finally, my editor, friend, and chemist extraordinaire, **James DeLuca.** Chemistry is Jim’s lifeblood. His knowledge of and passion for the subject created the many anecdotes on the industrial applications of liquid crystals which are sprinkled throughout the book. Jim answered questions, emails, and phone calls with patience, clarity, and his ever-present enthusiasm.

Biographies of the Author and Editor

Gregory Anthony DiLisi

Gregory Anthony DiLisi earned his Bachelor of Science degree, with distinction, from Cornell University in Applied and Engineering Physics. He then earned his Master of Science and Doctor of Philosophy degrees in Condensed Matter Physics from Case Western Reserve University. Since then, he has taught a wide range of physics courses at the high school, undergraduate, and graduate levels. He is currently at John Carroll University, where he has held appointments in two departments—physics and education. As a faculty member, he developed over sixteen courses on topics including: computational physics, experimental physics, instructional technology, interdisciplinary science, physics for engineers, problem-solving, science and society, and science methods. As an experimental physicist, he specializes in liquid crystals and complex fluids with publications appearing in peer-reviewed journals such as: *Journal de Physique II*, *Liquid Crystals*, *Microgravity Science and Technology*, and *Physical Review* A. His research focuses on the viscoelastic properties and surface interactions of oligomeric liquid crystals as well as the stability of liquid bridges as they shift from micro- to hyper-gravity environments. In the area of science education, his research initially focused on developing problem-solving strategies and team-building skills in undergraduate engineering and science students. However, his current research focuses on using case studies as a pedagogical approach to teaching physics. In these areas, he has publications appearing in peer-reviewed journals such as: *The Journal of College Science Teaching*, *The Journal of STEM Education: Innovation and Research*, and *The Physics Teacher*. He has been the Principal Investigator of externally-sponsored research through several grants from agencies such as: The American Association of Physics Teachers, The National Aeronautics and Space Administration, and The National Science Foundation. He was chosen to be the Ohio Educator Fellow for both of NASA's *Stardust* and *Cassini* space probes and serves as a consultant to numerous educational outreach initiatives. He has authored over forty peer-reviewed journal articles and is an international speaker, having presented at numerous scientific and educational conferences of various professional societies.

James Joseph DeLuca

James Joseph DeLuca received his Bachelor of Science degree in bio-chemistry. He worked in the private sector as an industrial chemist for over three decades. In this capacity, he worked at PPG Industries for thirteen years, where he conducted studies of pigment durability of exterior OEM coatings. He then spent ten years at Nippon Coatings as a Laboratory Manager, where he studied proprietary micro-to-nano aqueous emulsion technology and synthesis methods. Currently, he is the QC manager at Axalta Coatings Systems—Orrville where he oversees the company's laboratory and production development. Additionally, he conducts research and development for EnVont Nanotechnologies, LLC, where he explores quantum aqueous nano-technology and a novel synthesis platform technology. In 2016, he was granted an approved United States patent for Hybrid Vehicle Systems involving synthesis methods to create an environmentally-friendly, aqueous 4–6 nm hybrid zero-valent amorphous atomic metal within crystalline mixed metal-oxide nanocrystals.